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# Art. XIII.—*On the Relationship of the Epidiorite and the Granite at Barrabool Hills and Dog Rocks, near Geelong, Victoria.*

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(With Plate VI.)

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## Introduction.

Although the outcrops of Epidiorite (Greenstone) in the Geelong District have long been known, evidence of the relationship between the epidiorite and the associated granite has been lacking. Some time ago Dr. Summers suggested that the writer seek more evidence on the matter; the result of the work is embodied in the present paper.

The location of the outcrops of the two rocks is shown in the sketch map (Fig. 1). In this, however, relative proportions are indicated only approximately; e.g., the epidiorite at the Dog Rocks is represented as five large masses, whereas actually it occurs as a discontinuous line of boulders along the eastern flank of the hill.

The geology of the eastern portion of the map has been taken, with some simplification of the Kainozoic series, from the Quarter Sheets 24 N.E. and 24 S.E., mapped by R. Daintree in 1861-3. The geology of the western portion has been added by the writer.

## Previous Workers.

The earliest published description of the epidiorite was made by Prof. Ulrich in the Exhibition Descriptive Catalogue (1).

In 1916 a local syndicate attempted to work the epidiorite of Gleeson's Hill for monumental stone, and Messrs W. H. Ferguson, J. P. Kenny, and A. M. Howitt, of the Mines Department, reported on these activities during 1916-18.

The syndicate also submitted a sample of the rock to Professor Skeats in 1916, and he gave it the name Epidiorite.

The granite of the area under discussion is identical with that of the You Yangs, which has been described by Prof. Skeats (2).

Dr. Summers in a paper (3) on the origin of some Victorian igneous rocks, introduced the problem of the relationship of the epidiorite to the granite, and put forward a theory to explain their relations. He remarked, however, that the relationship he postulated could not be stated to have been proved owing to the inconclusive nature of the field evidence then available.

The relevant parts of the above literature are discussed in the succeeding pages.

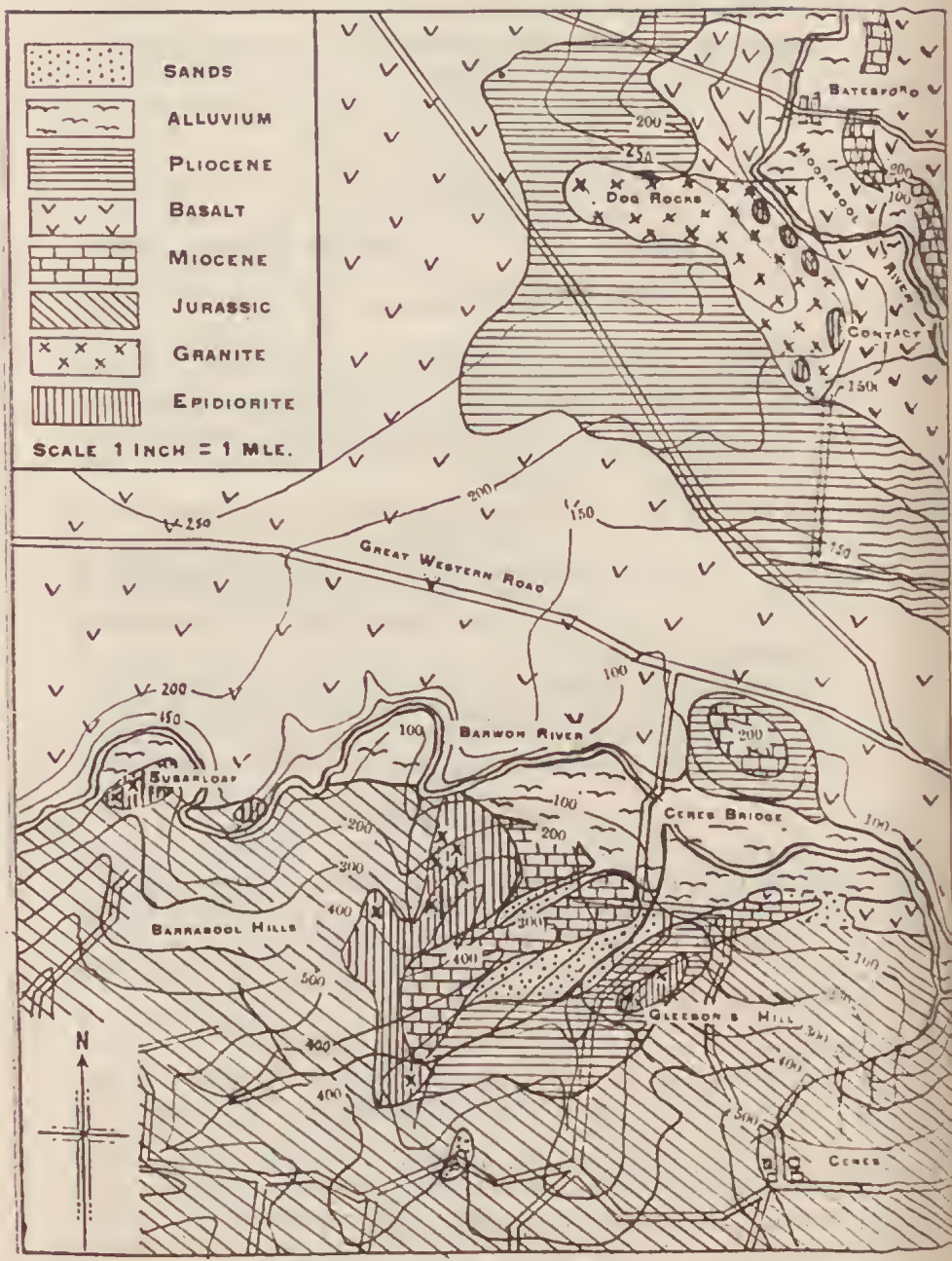


FIG. 1.—Sketch map to show location of outcrops of Epidiorite and Granite at Barrabool Hills and Dog Rocks in the Geelong District.

## Lithology.

### Epidiorite.

The typical epidiorite is a massive igneous rock, dark green in colour, very hard and tough. The unexpected hardness of the stone caused the syndicate to give up their project. A suitable quarry face could not be obtained, and the rather close rhomboidal jointing in the rock produced blocks unsuitable for working. Weathered blocks show an irregular hackly surface due to the removal of felspathic minerals by atmospheric weathering. A small amount of pyrite is disseminated throughout the rock, and thin incrustations of pyrite and molybdenite can occasionally be seen on some blocks. Alteration of the pyrite has led to the deposition of iron oxides in certain joints. Mr. J. P. Kenny, of the Mines Department, bearing in mind the similarity of this rock to the Western Australian greenstones, had an analysis made of the iron oxides. They showed a trace of gold and silver, but no platinum.

The rock has been called variously Trap, Hypogene, Gabbro Rock, Diallage Rock, Greenstone and Diabase, but in view of the present mineralogical composition it is best termed Epidiorite.

Prof. Ulrich (1) described the rock as "a coarsely crystalline granular mixture of light-green Labradorite and of a dark-green augitic mineral which according to its lustre and cleavage is Diallage." In corroboration of this determination, he quoted a chemical analysis by Mr. J. Cosmo Newbery: "40·06% is soluble in HCl, and the analysis of this portion proves it to be Labradorite, whilst the insoluble portion comes very near the mean composition of Diallage."

The petrographic description by Prof. Skeats reads: "Specimen 1843 (S 4664) from Ceres, near Geelong.

"*Hand Specimen.*—Rock dark in colour, of medium coarse texture. S.G. 2·93. One face has been polished. It takes a fair polish, but is not quite uniform owing to variation in the hardness of the constituent minerals.

"*Microscopic Characters.*—The rock originally consisted of crystals of Augite and Plagioclase felspar. It has been almost completely recrystallized, owing to stress by dynamic metamorphism, but does not show foliation. It now consists of the following minerals: Partially altered Plagioclase showing remains of lamellar twinning, Plagioclase completely altered and recrystallized to a granular aggregate of Albite felspar and Zoisite. The Augite in places remains partially unchanged, but for the most part is recrystallized as platy and fibrous masses of secondary Hornblende (Actinolite and Tremolite) and Chlorite. The original texture of the rock was probably medium grained, and it was probably a diabase or dolerite. In its present metamorphic condition it is perhaps best described as an Epidiorite."

Three microscopic sections of the normal type epidiorite examined by the writer agree closely with the above description by Prof. Skeats. Two were from the Dog Rocks and one from the Barrabool Hills. Partial recrystallization is universal throughout the normal epidiorite; uralitization of the original augite and diallage has converted them into actinolite and hornblende; saussuritisation of the plagioclase has produced a mosaic of albite, zoisite and epidote; chloritisation of the ferromagnesian minerals has also occurred, probably after the uralitization. Minute crystals of pyrite occur, rarely, in the normal rock.

A characteristic feature of the epidiorite in mass is the variation in texture. One block may show several bands, each of different grain-size, with sharp junctions between them. Even the finest grained material, however, is definitely massive igneous; no sign of tuffaceous character can be seen in a microscopic examination of this fine-grained material. The bulk of the rock is medium-grained, but varies from very fine to very coarsely crystallized rock, some of the amphiboles in the latter being up to 4 inches long. Thin irregular veins of white felspathic minerals traverse the epidiorite, and jointing has often occurred along these.

### Granite.

The granite of the Geelong district is limited to one type, a true acid granite, which outcrops at Maude, You Yangs, Dog Rocks and Barrabool Hills. Its petrography has been studied by Prof. Skeats (2). It is a pink-coloured coarse-grained granite with porphyritic felspars, and under the microscope is seen to consist of abundant quartz, orthoclase and subordinate plagioclase, biotite and some muscovite. The rock is susceptible to attack by atmospheric weathering agents, and crumbles away to coarse sand. No trace of recrystallization can be observed, and this is significant because the epidiorite is characteristically recrystallized.

Dr. Summers (3) has classed this granite with those of Cape Woolamai, Gabo Island and Mount Buffalo in his "Alkaline Group," of probable post-Ordovician and pre-Devonian age.

## Theories of the Relationship.

Three possibilities exist as to the relationship, viz.—

A.—Granite intrusive into Epidiorite.

B.—Granite and Epidiorite the differentiation products of one magma.

C.—Epidiorite intrusive into Granite.

Theory A.—The epidiorite is regarded, according to this theory, as roof-pendants on stocks of the underlying granite bathylith, to the upward movement of which the metamorphic changes in the epidiorite are ascribed.

This view, first proposed by Dr. Summers, is the one generally held, at any rate for the Barrabool Hills outcrops, and the result of the writer's work has been to confirm it.

Theory B.—This conception of the relations was advanced as an alternative by Dr. Summers (3). Noting that at Gleeson's Hill in the south a granite porphyry dyke is intrusive into the epidiorite, while at the Dog Rocks the epidiorite, in the form of what he regarded as veins, seemed to be intrusive into the granite, he suggested that "the two rocks were derived from a common magma by complementary differentiation, and that the basic differentiation product was intruded to the south and the acid portion to the north. At the time of intrusion the differentiation was not quite complete, and in the southern area the residual acid portion separated out and was intruded through the basic portion in the form of a dyke."

The "veins" of epidiorite at the Dog Rocks are not in contact with the granite, but are merely lines of boulders passing between boulders of granite, and no conclusion can safely be drawn from this source. The writer was fortunate in discovering a small dyke of granite intruding the epidiorite at the Dog Rocks, so that here, as well as at the Barrabool Hills, the granitic rock is intrusive.

Theory C.—After a hurried examination of the outcrop at Gleeson's Hill in 1918, Mr. A. M. Howitt, of the Mines Department, described the epidiorite there as "an elongated boss-like intrusion" into the granite. If this were correct, one would expect to find that the granite had been metamorphosed and that the epidiorite was the fresh rock, but as shown in the microscopic descriptions, the epidiorite has suffered from these changes while the granite has not.

It appears clear, therefore, that the granite is definitely intrusive into the epidiorite in both localities. The additional evidence obtained by the writer is interpreted in the light of this conclusion, and finally the origin and age of the epidiorite is discussed.

## Additional Evidence.

### 1. *Dyke of Granite at the Dog Rocks.*

This dyke occurs in the outcrop marked "Contact" on the map. It is about 5 inches wide, and passes at a steep angle through a boulder of epidiorite some 4 feet across, as shown in Plate VI., Fig. 4. The granite is fine-grained on either edge, but in the centre it is coarse-grained to pegmatitic, due no doubt to concentration of mineralizers there during injection. The dyke extends downwards into the main granite mass of the Dog Rocks, and clearly has intruded the epidiorite. The junction between the two rocks is quite sharp. A microscopic section of the junction of the two rocks shows that "contact" minerals are absent; the junction is quite sharp. Some limonite is present along the

junction as a product of weathering. The granite is the true acid type, with angular quartz, abundant felspars—orthoclase and subordinate plagioclase, biotite and a little muscovite. The epidiorite of this slide does not differ very much from the normal type. It consists of secondary hornblende, secondary felspar—albite, and zoisite, remains of the original augite and plagioclase, and chlorite.

The fact that the intrusion of the granite has not caused any marked departure from the normal character in the epidiorite shows that the thermal metamorphic effects were negligible even close to the granite. We must therefore seek another explanation of the partial recrystallization which is common throughout the epidiorite. It seems most probable that dynamometamorphism is the cause. The uralitization (paramorphic conversion of pyroxene to amphibole) is a feature characteristic of dynamometamorphism.

### 2. *Change from Granite to Granite Porphyry.*

In the Barrabools the best opportunity of studying the two rocks *in situ* is in the northern part of the large central outcrop. Here the epidiorite caps the hills as a long "reef" of boulders *in situ*, and appears to be about 100 feet thick. On the western slopes, where denudation has been most effective, the underlying granitic rock has been exposed as helmet-shaped boulders, about a dozen in number. A change in character of the rock in these boulders occurs as we ascend. At the foot of the hill, the rock is typical coarse-grained pink granite, with porphyritic felspars. Higher up it becomes a granite porphyry, showing two distinct generations of crystals, and is a parti-coloured rock, the felspar phenocrysts being pink and the groundmass of a grey colour. Just below the base of the epidiorite, the rock resembles a granodiorite porphyrite, the felspars being now white in colour, and the groundmass dark-grey.

This granite porphyry is also seen in the other Barrabool Hills outcrops, especially on the upper levels, and seems to be between the granite proper and the epidiorite. It is not present in the Dog Rocks outcrop of granite. The explanation of this porphyritic structure in minor intrusions is stated by Hatch (4) to be due to two phases of consolidation of the granitic magma: slow formation of phenocrysts in the abyssal magma followed by rapid crystallization of the interstitial liquid when the released semi-crystallized magma came into contact with the cool country rock (epidiorite) during its upward movement by magmatic stoping. The darker colour of the granodiorite porphyrite is possibly due to marginal assimilation of the epidiorite.

### 3. *Variation of texture in the epidiorite.*

This phenomenon, noted before, may be due to two causes. The dolerite or diabase from which the epidiorite has been derived

may have been extruded as a succession of lava flows, each crystallizing somewhat differently, producing the banded structure. These "bands" are only a few inches wide, and cannot be traced out as definite beds in the rock, as one would be able to do with tuffaceous beds.

Alternatively the structure may be due to recrystallization and partial flowage owing to stress by dynamometamorphism. This is not such a likely explanation, although pressure effects undoubtedly account for the occasional slickensided surfaces of amphibole on some of the epidiorite blocks, and also for the incipient foliation and orientation of minerals shown by the finer grained material. If the banding of textures were due to dynamometamorphism the development of foliation would be much more marked. The typical epidiorite, according to Hatch (4, p. 397) shows uralitization without the development of foliation.

4. *Incrustations of Pyrite and Molybdenite.*

The incrustations of sulphide minerals are very thin, and their location in joint planes points to a pneumatolytic or hydrothermal source, presumably the granite. "An impregnation by pyrite is always associated with the formation of greenstone, and pyrite is always secondary in saussuritized and uralitized rocks." (Weinschenk, 5, p. 151).

5. *Felspathic Veins in the Epidiorite.*

Irregular veins of white felspathic minerals traverse the boulders of epidiorite. Under the microscope the felspar proves to be a recrystallized albite-zoisite mosaic, probably due to the dynamometamorphism of the rock, when partial fusion under pressure would result in the segregation of the different minerals, and their recrystallization in veins.

6. *Coarsely crystallized Epidiorite, containing quartz, etc.*

Several slides made of this material yielded some very interesting information regarding the mineral changes. They are therefore described in some detail.

No. 2. Macroscopic.—Very coarse-grained epidiorite, with large crystals of quartz and felspar, but very little ferromagnesian minerals. George's Hill, central outcrop, Barrabool Hills.

Microscopic.—The most abundant mineral is secondary quartz, with undulose extinction. Next comes analcite, completely isotropic, in colourless compact masses. The groundmass consists of a granular mixture of quartz, recrystallized felspar, and chlorite. A small amount of augite with peripheral secondary hornblende is present.

No. 3. Cut from the same piece as No. 2.

Microscopic.—The secondary quartz in this section has corroded the edges of the hornblende and chlorite, and is evidently

an admixture from an outside source. Analcite, secondary hornblende and chlorite are present. In one part there is a good example of uralitization—a crystal of diallage surrounded by secondary hornblende. Minute crystals of accessory ilmenite are scattered through the section.

No. 4. Macroscopic.—Coarse-grained epidiorite, George's Hill, central outcrop, Barrabool Hills.

Microscopic.—Secondary quartz is abundant; it is evidently a later admission to the rock, for it has corroded the portions of the other minerals nearest it. A large crystal of labradorite is remarkable for its freshness and broad lamellar twinning. That portion of it nearest the quartz is, however, recrystallized to albite and zoisite. Secondary actinolite, in the form of large crystals and clusters of fibrous needles, is common, and remnants of diallage crystals can be seen enclosed by the actinolite. Several patches of dark-coloured minerals proved to be ilmenite (partly altered to leucoxene) and a brown mineral possessing the optical properties of micaceous ilmenite.

No. 5. Macroscopic.—A specimen of normal epidiorite traversed by small veins of quartz. Gugger's Hill, central outcrop, Barrabool Hills.

Microscopic.—The commonest minerals are secondary actinolite and fibrous secondary hornblende, both formed by the uralitization of augite, some of which remains. The veins of secondary quartz traverse the section, and have corroded the edges of the ferromagnesian minerals. Analcite is present in small amount, also chlorite, pyrite and ilmenite.

The study of these sections reveals two additional mineral changes, silicification and analcitisation, resulting in the formation of secondary quartz and analcite respectively. These changes involve the introduction of new material from without, and the source is probably the juvenile waters of the granitic magma. Probably the bands of coarse-grained epidiorite correspond to joint planes in the original rock, and along these travelled the mineralized waters from the intruding granite. Partial solution of the rock on either side of the joint plane would occur, and the whole would slowly crystallize to form the coarse material now seen.

## Review of the Metamorphic Changes.

In the normal epidiorite, the changes have been induced by dynamometamorphism, and include uralitization, saussuritization, epidotisation, and chloritisation. It is reasonable to assume that the great pressure which caused the changes was due to the upward-moving granite. The fracturing of the epidiorite would open up passages for the circulation of gases and thermal waters, and thus facilitate the hydrothermal changes, silicification and analcitisation, which took place in those passages. The sulphide minerals would form in the cracks more remote from the granite.

## Age and Probable Origin of the Two Rocks.

Boulders both of epidiorite and of granite occur in the Jurassic basal conglomerate, which is exposed in a river cliff on the east bank of the Barwon, some two miles east of Ceres Bridge. They are both therefore pre-Jurassic in age.

Professor Skeats (2) has demonstrated that at the You Yangs granite of the Alkaline Group is post-Lower Ordovician, since it has intruded and metamorphosed sediments which are probably of that age. The Alkaline Group is regarded (3) as being older than the Victorian granodiorites, which are classed as Devonian. The granite must therefore have been intruded in the post-Lower Ordovician, post-Upper Ordovician, or post-Silurian orogenic periods.

The epidiorite, having been intruded by the granite, is obviously older than the latter, and its age is best arrived at by analogy with similar Older Palaeozoic rocks. A very good correlation can be made on field relations, lithological facies and mineral changes, between the Geelong epidiorite and the widespread Heathcotian (Upper Cambrian) series, which outcrop at Heathcote (5), Monegetta and Lancefield (6), Howqua River (7), Tatong (8), Dookie and Mt. Stavely.

The Heathcotian series of basic igneous rocks, diabases in part, have suffered albitisation, silicification, chloritisation, uralitization, formation of carbonates, and the development of the mineral lawsonite. There are associated with the diabase conformable beds of submarine tuffs, cherts and black slates. Professor Skeats has demonstrated that the diabases represent Upper Cambrian submarine lavas, which were succeeded by tuffs in which trilobites and *Protospongia* spicules of Upper Cambrian age have been found, and then by true sedimentary beds in which Lower Ordovician fossils occur. The tuffs have been silicified by metasomatic action, and are now cherts. The albitisation is possibly due to the absorption of sodium from the sea-water. Pillow-lava structure can be seen in places.

The Geelong epidiorite is exclusively igneous; nothing to correspond to the tuffaceous and sedimentary beds of the type area is present. For this reason fossil evidence of age is wanting. But the mineral changes are very similar to those experienced by the Heathcotian diabases. The analcitisation noted in some of the epidiorite may be due to the action of sea-water, but other common spilitic characters are absent, so that the analcite may have come from magmatic waters.

The chemical analyses (1) and (3) of the two rocks show certain differences; the epidiorite averages 2 or 3% higher in CaO and MgO than the Heathcote or the Howqua River diabase, but is 5% lower in iron oxides. However, these differences might be expected in rocks so widely separated in distance.

There is no other Lower Palaeozoic rock in Victoria with which a correlation can be made, and on the whole it appears best to class the epidiorite with the Heathcotian.

It has been suggested that the Heathcotian lavas formed an extensive sheet in Victoria, and that the outcrops now exposed represent anticlinal ridges in this sheet. Thus the Colbinabbin Range near Heathcote is pictured as an eroded anticlinal ridge, and the fact that if the axis of this range were produced southwards, it would pass through the Geelong outcrops of epidiorite, has been thought to indicate some relation between the two areas. Bearing this in mind, the writer made a careful search of the You Yangs, which would also coincide with the axis, to see if anything of the nature of diabase or epidiorite occurred there. A few blocks of a very dark rock, slightly greenish, were found, but they proved to be a differentiation from an unrecorded dyke of felspar porphyrite, about 20 yards wide, which runs for about 1½ miles through the middle of the granite mass. A microscopic examination of the greenish rock showed it to be a dolerite, quite fresh and without any sign of recrystallization. This negative evidence regarding the anticlinal ridge inclines one to the belief that the Geelong outcrop, at least, is a flow of lava from a vent independent of the Heathcote area, although the magmatic basin from which the lava came was probably connected, in depth, with all the vents.

There is no absolute evidence that the epidiorite was originally extruded as a submarine lava, and the absence of associated sediments seems to indicate a possibly terrestrial flow.

## Conclusion.

On the evidence presented, the epidiorite must be regarded as a Heathcotian (Upper Cambrian) extrusion of massive dolerite or basalt, not necessarily spilitic in character, and possibly local in extent to the Geelong district. During the interval between the Lower Ordovician and the Lower Devonian the rock suffered dynamometamorphism, resulting in partial recrystallization throughout, and was also intruded and probably uplifted by an acid granite of the Alkaline Group. Hydrothermal action was more pronounced than thermal metamorphism during this intrusion, and caused the formation of the bands of coarsely-crystallized material.

Denudation since the Palaeozoic has removed a great deal of the epidiorite, so that now the rock outcrops as roof-pendants on the granite.

## Acknowledgments.

I received much valuable advice during the progress of the work, particularly in the microscopic determinations, from Associate-Professor H. S. Summers, D.Sc., and my sincere thanks are

Fig. 1.

Fig. 2.

Fig. 3.

A.C. photo

Fig. 4.

Epidiorite and Granite. Geelong, Victoria.